Response to Closeout for iTPC Technical Cost, Schedule, and Risk Review

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The review committee has requested a document describing the physics impact of running in RHIC FY19 with a shorter run or previous generation of electronics mounted on new iTPC sectors.

The run planning for a shortened run in FY19:

The STAR collaboration has already been working with the BNL Collider Accelerator Division (CAD) to optimize the strategy for runs in FY19 and 20. These discussions were prompted by the need for commissioning time for the Low Energy RHIC electron Cooling (LEReC) hardware and from a CAD re-evaluation of the expected performance improvements even without LEReC. The original LEReC plan had called for construction of a DC superconducting RF electron gun and a 704 MHz booster cavity to supply cooling beams for the 7.7 and 9.1 GeV colliding energies, and for a second booster cavity to be installed prior to FY20 to provide cooling beams for the 11.5, 14.5 and 19.6 GeV colliding energies. It is now expected that luminosity improvements of three times (above FY2011 and FY2014 rates) can be achieved for the 14.5 and 19.6 GeV collision energies even without LEReC. The weeks necessary for commissioning of the second cavity would be larger than the expected savings in running time for those two energies; therefore the decision was made not to construct the second cavity. It is also expected that by raising the voltage on the booster cavity from 2.1 to 2.5 MV, cooling could be provided for the 11.5 GeV collision energy. The revised strategy is to run the highest energies first and interleave commissioning of the LEReC system (total of 6 weeks for commissioning). Short runs at 62.4 GeV have been added to each year to provide a systematic cross check between the two years of BES-II operations. In addition, fixed target (FXT) taken during the 62.4 GeV running will be at 7.7 GeV center of mass energies, which provides a cross check between the FXT and standard systematics. CAD has also provided improved estimates of the expected luminosities. This allows the following run plan, assuming 24 weeks of cyro operations in FY19 and FY20:

Run	Energy	Weekly Integrated Luminosity	Duration	Goals	priority	Sequence
19	**$\sqrt{s_{NN}}$=19.6 GeV**	**49 μb^{-1}**	**4.5-wk**	**400M mbias**	**2**	**1**
	$\sqrt{s_{NN}}$=14.5 GeV	**23 μb^{-1}**	**5.5-wk**	**300M mbias**	**1**	**2**
	$\sqrt{s_{NN}}$=11.5 GeV	**24 μb^{-1}**	**4.9-wk**	**230M mbias**	**3**	**3**
	$\sqrt{s_{NN}}$=62.4 GeV (($\sqrt{s_{NN}}$=7.7 GeV FXT)	**450 μb^{-1}**	**1-wk Concurrent**	**400M mbias 200M mbias**	4	4

	Commissioning		**6 wk**			
20	**$\sqrt{s_{NN}}$= 9.1 GeV**	**6.8 μb^{-1}**	**9.5-wk**	**160M mbias**	**2**	**2**
	$\sqrt{s_{NN}}$ =7.7 GeV	**2.0 μb^{-1}**	**12.1-wk**	**100M mbias**	**1**	**1**
	$\sqrt{s_{NN}}$=62.4 GeV ($\sqrt{s_{NN}}$=7.7 GeV FXT)	**450 μb^{-1}**	**1-wk Concurrent**	**400M mbias 200M mbias**	**3**	**3**

Table 1: A possible strategy for runs 19 and 20 using the current best estimates for expected luminosities and for 22 weeks of physics running each year (24 cryo-weeks).

Postponing the start of operations by six weeks in FY19 will shorten that run as it is not possible to extend RHIC running into the summer months. We would propose that the run in FY20 would start six weeks earlier (mid-November of 2019 rather than January of 2020) in order to recover the necessary time for physics running. It would be necessary to move the 11.5 GeV collision energy to FY20 and to reduce the commissioning time for the LEReC to 5 weeks in FY19. Shifting running time from FY19 to FY20 would result in no impact to the physics program.

Run	**Energy**	**Weekly Integrated Luminosity**	**Duration**	**Goals**	**priority**	**Sequence**
19	**$\sqrt{s_{NN}}$=19.6 GeV**	**49 μb^{-1}**	**4.5-wk**	**400M mbias**	**2**	**1**
	$\sqrt{s_{NN}}$=14.5 GeV	**23 μb^{-1}**	**5.5-wk**	**300M mbias**	**1**	**2**
	$\sqrt{s_{NN}}$=62.4 GeV ($\sqrt{s_{NN}}$=7.7 GeV FXT)	**450 μb^{-1}**	**1-wk Concurrent**	**400M mbias 200M mbias**	**3**	**3**
	Commissioning		**5 wk**			
20	**$\sqrt{s_{NN}}$=11.5 GeV**	**24 μb^{-1}**	**4.9-wk**	**230M mbias**	**3**	**3**
	$\sqrt{s_{NN}}$= 9.1 GeV	**6.8 μb^{-1}**	**9.5-wk**	**160M mbias**	**2**	**2**
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	$\sqrt{s_{NN}}$=62.4 GeV ($\sqrt{s_{NN}}$=7.7 GeV FXT)	**450 μb^{-1}**	**1-wk Concurrent**	**400M mbias 200M mbias**	**4**	**4**

Table 2: An alternate strategy with run 19 shortened by six weeks and run 20 increased.

Physics impact of a shortened run in FY19:

If it is not possible to start run 20 early (in November 2019), and the FY20 run is limited to 24 cryo-weeks, there would be an impact on the physics program. The impact of options can be assessed based on the estimates of the event statistics necessary to achieve the various physics goals (outlined in the BES-II proposal). These are shown in the table below:

Collision Energies (GeV):	**7.7**	**9.1**	**11.5**	**14.5**	**19.6**
Chemical Potential (MeV):	**420**	**370**	**315**	**260**	**205**
Observables	Millions of Events Needed				
R_{CP} up to p_T 4.5 GeV	NA	NA	160	92	22
Local Parity Violation (CME)	50	50	50	50	50
asHBT (proton-proton)	35	40	50	65	80
Directed Flow studies (v_1)	50	75	100	150	200
net-proton kurtosis ($\kappa\sigma^2$)	80	100	150	200	300
Elliptic Flow of ϕ meson (v_2)	100	150	200	300	400
Dileptons	100	160	230	300	400
Proposed Event Goals:	**100**	**160**	**230**	**300**	**400**

Table 3: The statistics needed to achieve various physics goals at all proposed energies.

Reducing the running time by about 30% at any energy will not compromise the net-proton kurtosis, directed flow, HBT, CME, or R_{CP} measurements, but it may reduce the significance of the dilepton and ϕ v_2 results. Fortunately, for both of these measurements, the iTPC upgrade will provide significant improvements, which could provide some compensation for the reduction in event statistics. The ϕ measurement relies on the ability to identify both daughter kaons. The iTPC extends the rapidity coverage by 50% for kaons that can be identified using dE/dx in the TPC and by 25% for kaons that need TOF for PID (the eTOF will only be on the East side of STAR). The dilepton measurement is considered to be the more important of these two measurements. The key physics goal is to study the dielectron excess invariant mass spectra in the low mass region (LMR) as a function of beam energy. The iTPC upgrade will reduce the systematic uncertainties due to hadron contamination, efficiency corrections, acceptance differences between unlike-sign and like-sign pairs, and cocktail subtraction. These improvements will result in a factor of 2 improvement in the systematic uncertainties for the dielectron excess yield (see Fig. 1). In addition, the iTPC will extend the acceptance of low-momentum electrons from $p_T > 0.2$ to $p_T > 0.1$ GeV/c. This improves the acceptance of the dielectron measurement by more than a factor of 2 in the low mass region ($0.4 < \text{mass} < 0.7$ GeV/c^2), therefore lowering the statistical uncertainties as well. With these improvements from the iTPC, we will be able to distinguish models with different ρ-meson broadening mechanisms; for example, the Parton-Hadron String Dynamic (PHSD) transport model versus Rapp's microscopic many-body model with macroscopic medium evolution (see the left panel of the figure below). Knowing the mechanism that causes in-medium ρ broadening and its temperature and baryon-density dependence is fundamental to our understanding and assessment of chiral symmetry restoration in hot QCD matter. The right panel of the figure below shows the projection of measurements from STAR from BES-II and data already taken at higher beam energies together with model calculations. STAR detector with RHIC BES-II program covers the unique energy range where the excitation function of LMR excess for collision energy between 20 and 200 GeV depends on initial temperature and for collision energy below 20 GeV on baryon density. Should it not be possible to acquire to full event statistics at each energy, we would devise a careful strategy to minimize the impact on the physics goals of the di-lepton program.

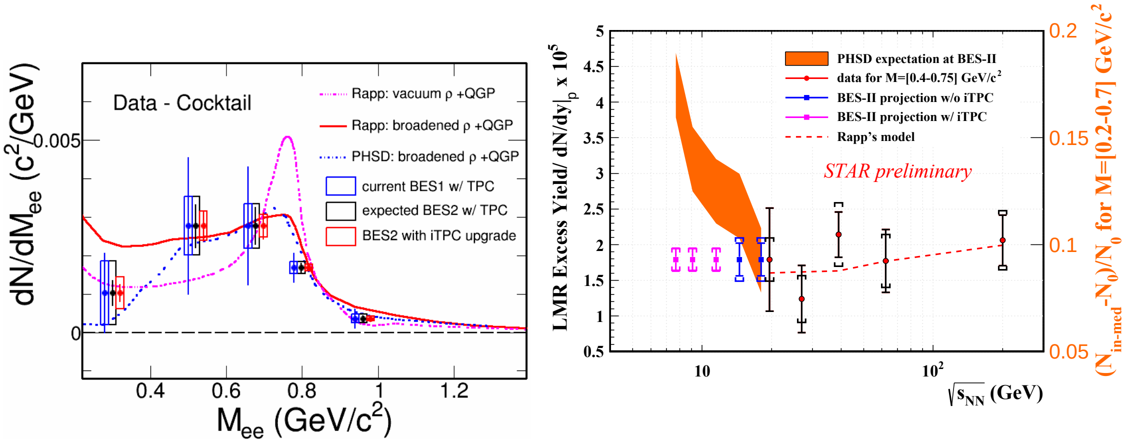

Figure 1 (Left panel): Dielectron invariant mass spectrum in the STAR acceptance ($|y_{ee}| < 1$, $0.2 < p_T < 1.4$ GeV/c, $|\eta| < 1$) after efficiency corrections, in Au+Au collisions at $\sqrt{s_{NN}}$ = 19.6 GeV. Theoretical calculations of a broadened ρ spectral function are shown up to 1.5 GeV/c^2 for comparison. The expected dielectron excess invariant mass spectra in Au+Au collisions at $\sqrt{s_{NN}}$ = 19.6 GeV in BES-II are shown with and without the iTPC upgrade. Comparisons to PHSD and Rapp's model calculations are also shown. (Right panel): Beam Energy dependence of Low-Mass dielectron excess from published data at 19.6 and 200 GeV, model expectation from PHSD for energy below 20 GeV and Rapp's model above 20 GeV. Also shown are sys. and stat. errors from preliminary results at 27, 39 and 62.4 GeV, and projections for BES-II. The projections at 7.7, 9.1 and 11.5 GeV are done with the iTPC. Projections for 14.5 and 19.6 GeV are done without the iTPC. The projection without iTPC for each energy has x2 ($\sqrt{2}$) bigger sys. (stat.) errors than that with iTPC, given the same number of events.

Instrumentation strategy for using the old TPC electronics in FY19:

We are responding to the iTPC Reviewers' comment regarding the backup mitigation option of the readout of every 2nd pad row of the new iTPC 40-row pad plane using STAR TPC's old electronics in case the SAMPA chip schedule slips.

We agree with the Reviewers' suggestion that we should prove to ourselves that this option is physically possible. We decided that the simplest path is to re-do the current mapping of the pads ⇔ connectors/pins map to make absolutely sure that this scheme will work. We proceeded with this plan and we have completed the new mapping. The new scheme guarantees (up to) 32 pads from even or odd pad rows for *every* connector on the pad plane. While certain board traces are now slightly longer, we don't think this will make an appreciable difference to the capacitive noise.

The new pad plane scheme is graphically shown below (Fig. 2):

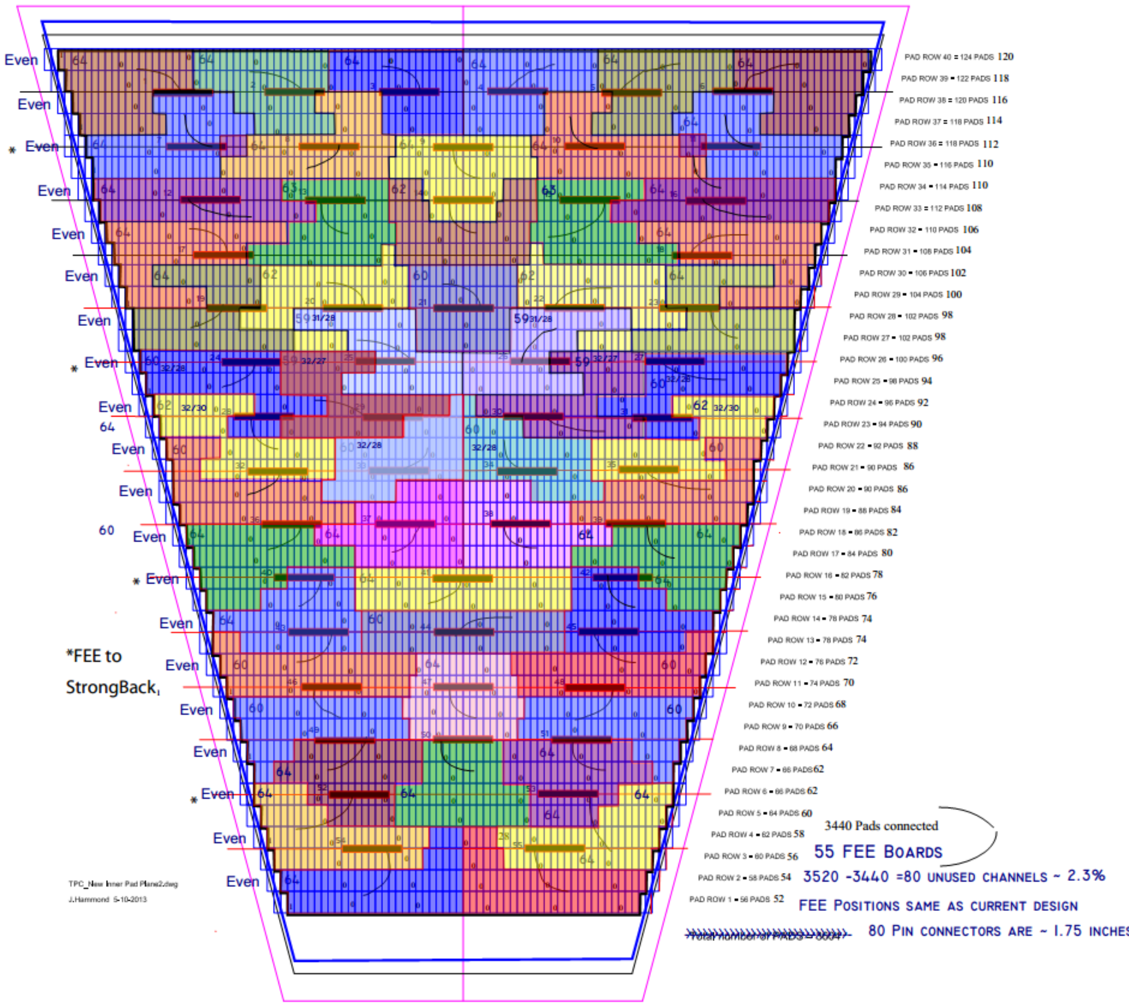

Figure 2: Layout of the padplane with the new option. Each colored area indicates the pads belonging to a given connector. Each connector connects up to 32 even and 32 odd pads from even and odd rows.

Once we decided to embark on this effort, we also took the opportunity to make the maps such that we only need one adaptor type (instead of potentially 55). To make this as simple as possible, we assigned odd pad rows to one side of the connector and even pad rows to the other. We can now either use an “odd” adaptor type that will pick up only odd rows, or we can use the “even” adaptor type that will only pick up even rows. This decision is relatively unimportant so it will be made at a later time. These are very simple passive adaptors which bridge one connector type to another so they don’t represent a major engineering or cost item.

We plan to manufacture both sets of adapters in enough quantity to be able to cover one sector’s worth of connectors (55) and use them to test the MWPC chambers in Shandong University throughout both their prototyping and final production stage. This test can thus be done using our old electronics without the need to wait for SAMPA chips of any number.

Physics impact of instrumenting every 2nd pad row for the inner sectors:

A full GEANT model of the detector configuration with only every 2nd row of the inner sectors has been prepared and HIJING events have been run through the simulator to study the impact of this detector configuration option. The main effects that the iTPC project has are to extend the pseudorapidity coverage and to improve the dE/dx resolution.

The figure below (Fig. 3) shows a comparison of the tracking efficiency as a function of pseudorapidity for the current TPC configuration (red) and for the configuration with upgraded inner sector pad planes with only every 2nd pad row instrumented (black points, labeled as iTPC/2). From Fig. 3, it is evident that the pseudorapidity coverage remains unchanged, but there is an increase in the overall tracking efficiency for pseudorapidities less than one.

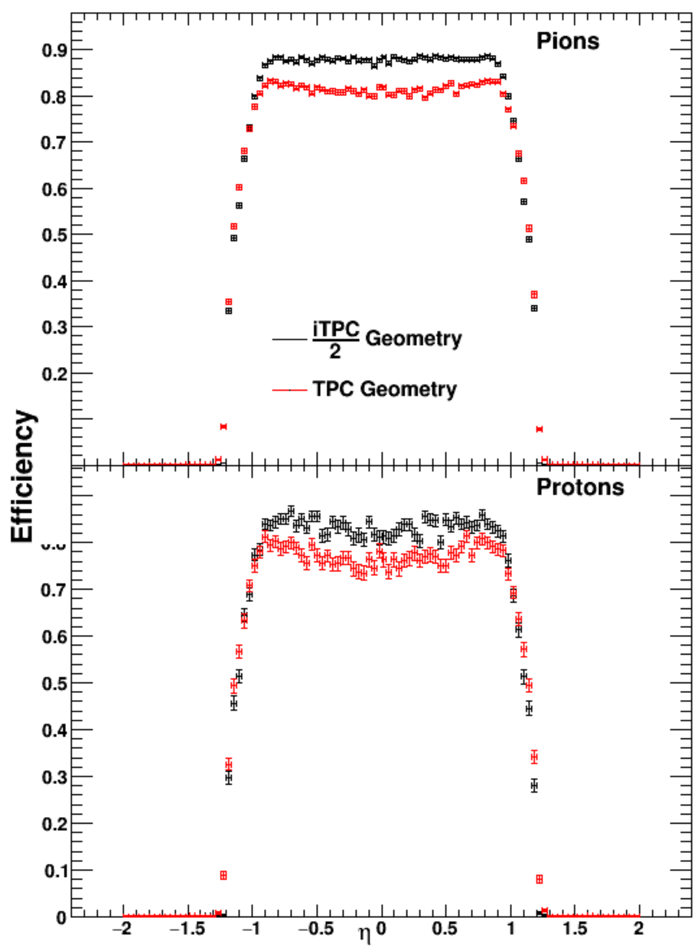

Figure 3: Geant-based comparison of the pion and proton tracking efficiency as a function of pseudorapidity for the current TPC configuration (red) and for the configuration with upgraded inner sector pad planes with only every 2nd pad row instrumented (black points, labeled iTPC/2).

The most important physics analysis made possible with the extended pseudorapidity coverage provided by the iTPC was the study of the net-proton kurtosis as a function of rapidity bin width (Δy_P). Figure 4 shows the expected sensitivities at the 7.7 and 19.6 GeV collision energies. These are the energies at which we observe the largest positive and negative values, respectively. Firmly establishing the trends at these two energies could conclusively demonstrate the change predicted by critical behavior. The impact on the physics of the net-proton kurtosis studies could be reduced by selecting to run these two energies in 2020. This would be an alternative to the run strategy indicated previously. By running the 19.6 GeV system in 2020, it would put more of a burden on the timely commissioning of the electron cooling, as we would need to run the 9.1 GeV collision energy in 2019.

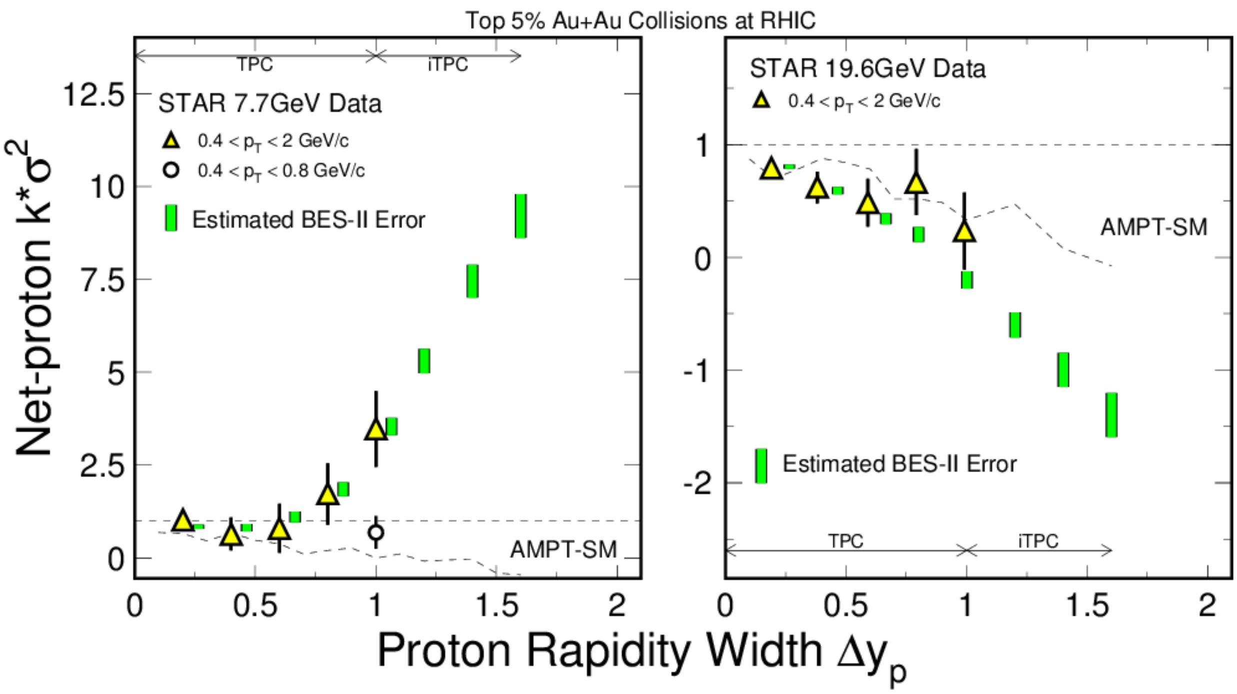

Figure 4: Net-proton kurtosis times squared standard deviation versus rapidity bin width for protons, for centrality 0-5% Au+Au collisions at 7.7 GeV (left panel) and 19.6 GeV (right panel). The green bars show the expected errors with BES-II data over the Δy_P region covered by the current TPC, and over the new region opened up by the iTPC.

The full GEANT simulation has allowed us to detail the dE/dx improvement provided with the configuration that instruments every 2nd inner sector pad row. Figure 5 shows the dE/dx resolution as a function of track length for the current TPC configuration (blue) and for the iTPC/2 configuration (red). The dE/dx resolution improves for long tracks from about 7.2% to about 6.5%. This is about half the improvement that would be provided with all iTPC pad rows instrumented. The primary physics impact of the improved dE/dx resolution is better electron/pion separation, and this improves dilepton studies. Figure 1 showed the expected error bars for the LMR excess in various configurations. Even with only every 2nd inner pad row instrumented, there is still improved performance in the dilepton studies.

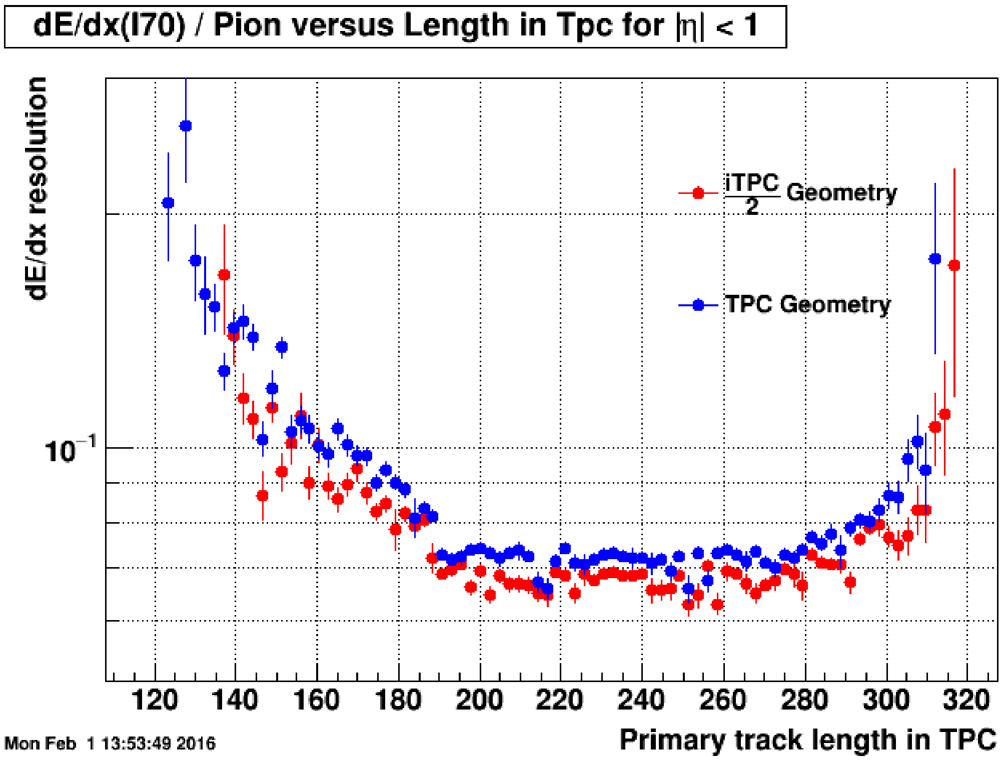

Figure 5: The dE/dx resolution of the current STAR TPC (blue points) compared to the projected dE/dx resolution of the iTPC/2 configuration, where only every 2nd inner pad row is instrumented (red points).

The iTPC/2 simulations indicate that the additional directed flow physics from the extended rapidity acceptance of the iTPC would not be realized until run 20. In the iTPC/2 scenario, two or three of the five BES-II energy points, in the vicinity of the so-called "softest point collapse of flow", would be fully probed in 2020 over the wider range of rapidity opened up by the iTPC. It is also important to note that a recent theoretical study (Nara et al., arXiv:1601.07692) stresses that future directed flow measurements should focus on $\sqrt{s_{NN}}$ near 10 GeV and below. Therefore, even in the iTPC/2 scenario, it will be possible to characterize the pattern of directed flow in this wider rapidity range at the beam energies of high theoretical priority.

Summary

The physics agenda of the original BES-II program can be achieved with either of the two fall back scenarios considered, however in either case there will be some cost to the anticipated improvements provided by the iTPC upgrade. In the scenario in which run FY19 is shortened, there will be increased error bars for the dilepton measurements for the middle collision energies unless the lost time in FY19 can be added to the FY20 run. In the scenario in which the old electronics is used in FY19 run, the kurtosis study will be limited to $\Delta y < 0.8$ for the FY19 collision energies.